Some Studies on the Impact of SB2009 on ILC Physics

Jim Brau

representing

the SB2009 Physics and Detectors Working Group

SB2009 Working Group

- Sakue set up working group to study SB2009 and communicate with the GDE in a systematic way:

Jim Brau (convener)
Mark Thomson(ILD)
Stewart Boogert(ILD)
Tom Markiewicz(SiD)
Takashi Maruyama(SiD)
Karsten Buesser(MDI)
Akiya Miyamoto (Software)
Keisuke Fujii (Physics)

Mikael Berggren(ILD),
David Miller(ILD),
Tim Barklow(SiD),
Noman Graf(SiD),

Understanding Matter, Energy, Space and Time: the Case for the Linear Collider

- More than 2700 scientists signed 2003 statement, expressing the world-wide consensus for the linear collider:
  - Understanding the Higgs boson
  - New discoveries beyond the standard model
  - The benefit of precision measurements and the interplay of LHC and LC
  - Cross connections
    between LC experiments, neutrino and quark studies, cosmological and astrophysical measurements, and HE nuclear physics.

Understanding the Higgs boson

- The linear collider offers accurate, model independent measurement of Higgs particle properties
  - Mass, width, couplings
- Should electroweak symmetry be broken in more complicated way than suggested by standard model, these accurate measurements
  - together with new very precise studies of the W and Z bosons and the top quark

  will constrain the possibilities and point the way to understanding

New discoveries beyond the standard model

- While the standard model with the simplest Higgs boson agrees well with all observations, there are strong reasons for believing in additional new physics
- There are at least two disparate energy scales:
  - the Planck scale at about 10^{19} GeV
  - the electroweak scale at a few hundred GeV
- Also, the strengths of the strong, electromagnetic and weak forces become similar at about 10^{16} GeV suggesting the possibility of grand unification
- These features suggest new physics at TeV scale
  - Candidates: SUSY, extra dimensions, other new particles, …

New discoveries beyond the standard model

- Grand unification
  - extrapolation to higher energies with the simple standard model fails to provide exact unification
    - some new physics is required at 100 – 1000 GeV
- Disparate energy scales (Electroweak and Planck)
  - cannot be understood in the standard model
  - Higgs, W, Z boson masses are all unstable to quantum fluctuations and naturally rise to Planck scale without new physics at few hundred GeV
- This suggests the standard model with a Higgs boson will be supplemented with new phenomena at the TeV scale which can be discovered by LC or LHC.

The benefit of precision measurements and the interplay of LHC and LC

- Two distinct/complementary paths to understanding of the structure of matter, space and time.
  - Direct discovery of new phenomena with operating at the energy scale of the new particles.
  - Inference of new physics through the <u>precision measurement</u> of phenomena at lower energy
- Historical record of these two paths working together to make more complete understanding
  - e^+e^- pointed to top quark, which Tevatron discovered
  - Precision data from both for current Higgs prediction
  - Z discovered at h-coll, precision understanding e^+e^-
  - Gluons and role in QCD

RDR vs ILC Physics Goals

- E_{cm} adjustable from 200 – 500 GeV
- Luminosity → $\int L dt$ = 500 fb^{-1} in 4 years
- Ability to scan between 200 and 500 GeV
- Energy stability and precision below 0.1%
- Electron polarization of at least 80%

- The machine must be upgradeable to 1 TeV

The RDR Design meets these "requirements," including the recent update and clarifications of the reconvened ILCSC Parameters group!

SB2009 Parameters

- GDE Physics Questions Committee

	RDR			SB2009 w/o TF				SB2009 w TF			
CM Energy (GeV)	250	350	500	250.a	250.b	350	500	250.a	250.b	350	500
Ne- (*10^{10})	2.05	2.05	2.05	2	2	2	2.05	2	2	2	2.05
Ne+ (*10^{10})	2.05	2.05	2.05	1	2	2	2.05	1	2	2	2.05
nb	2625	2625	2625	1312	1312	1312	1312	1312	1312	1312	1312
Tsep (nsecs)	370	370	370	740	740	740	740	740	740	740	740
F (Hz)	5	5	5	5	2.5	5	5	5	2.5	5	5
γex (*10^{-6})	10	10	10	10	10	10	10	10	10	10	10
γey (*10^{-6})	4	4	4	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
βx	22	22	20	21	21	15	11	21	21	15	11
βy	0.5	0.5	0.4	0.48	0.48	0.48	0.48	0.2	0.2	0.2	0.2
σz (mm)	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
σx eff (*10^{-9} m)	948	802	639	927	927	662	474	927	927	662	474
σy eff (*10^{-9} m)	10	8.1	5.7	9.5	9.5	7.4	5.8	6.4	6.4	5.0	3.8
L (10^{34} $cm^{-2}s^{-1}$)	0.75	1.2	2.0	0.2	0.22	0.7	1.5	0.25	0.27	1.0	2.0
δE %	0.6	1.2	2.4	0.3	0.6	1.6	4.1	0.3	0.6	1.6	3.6
Npairs* 10^3	97	156	288	48.7	97.4	214	494	57.4	115	255	596
$\mathcal{L}$	0.75	1.2	2.0	0.2	0.22	0.7	1.5	0.24	0.27	1.0	2.0
$\mathcal{L}_{(1\%)}/\mathcal{L}$	0.97	0.92	0.83	0.98	0.96	0.88	0.73	0.94	0.89	0.77	0.72

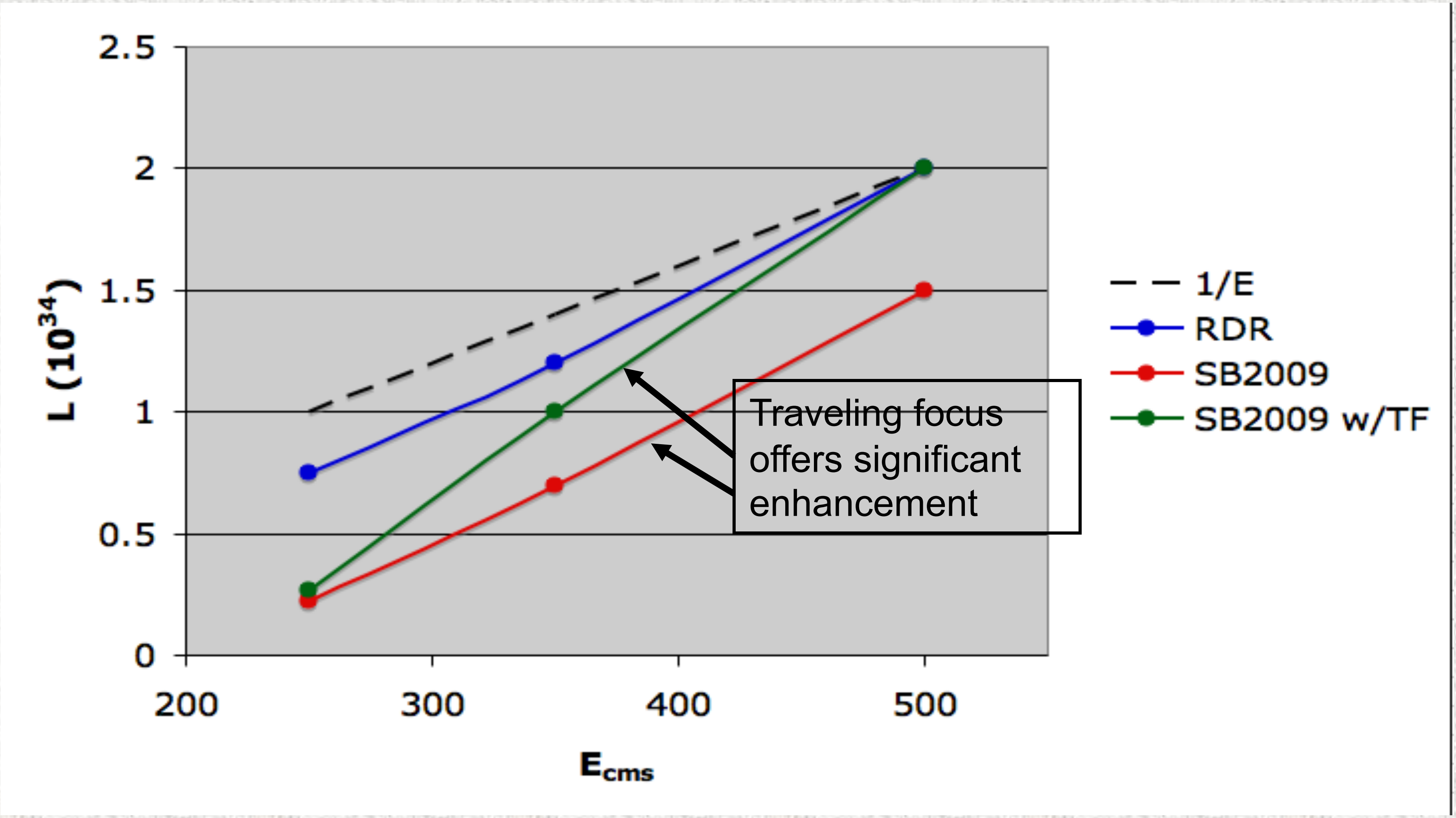
SB2009 compared to RDR design

- **E_{cm} adjustable from 200 –500 GeV**
  - Yes, but much lower luminosity at lower energy
- **Luminosity → $\int Ldt$ = 500 fb^{-1} in 4 years**
  - Reduced low E luminosity means stretch out
- **Ability to scan between 200 and 500 GeV**
  - With reduced luminosity, especially at lowest energies
- **Energy stability and precision below 0.1%**
  - Same
- **Electron polarization of at least 80%**
  - Same
- **The machine must be upgradeable to 1 TeV**
  - Same

SB2009

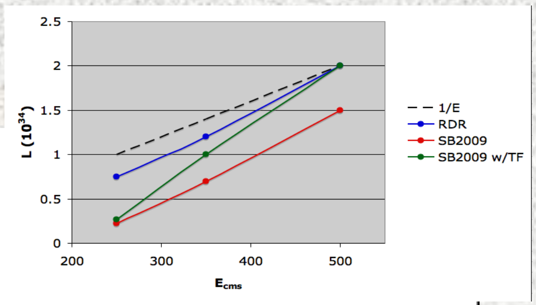
- Particular concern for good Higgs threshold luminosity and for energy scans at the threshold for light new states
- Increased beamstrahlung reduces useful luminosity
- Beam energy spread
  - limiting factor for the LoI studies of Higgs recoil mass analysis (RDR parameters)
- Increased backgrounds impact detector performance
  - may reduce marginal space between the beamstrahlung pairs and the beam pipe
  - may damage inner acceptance of the forward calorimeters (LumiCAL/BCAL) reducing the hermeticity of the detector

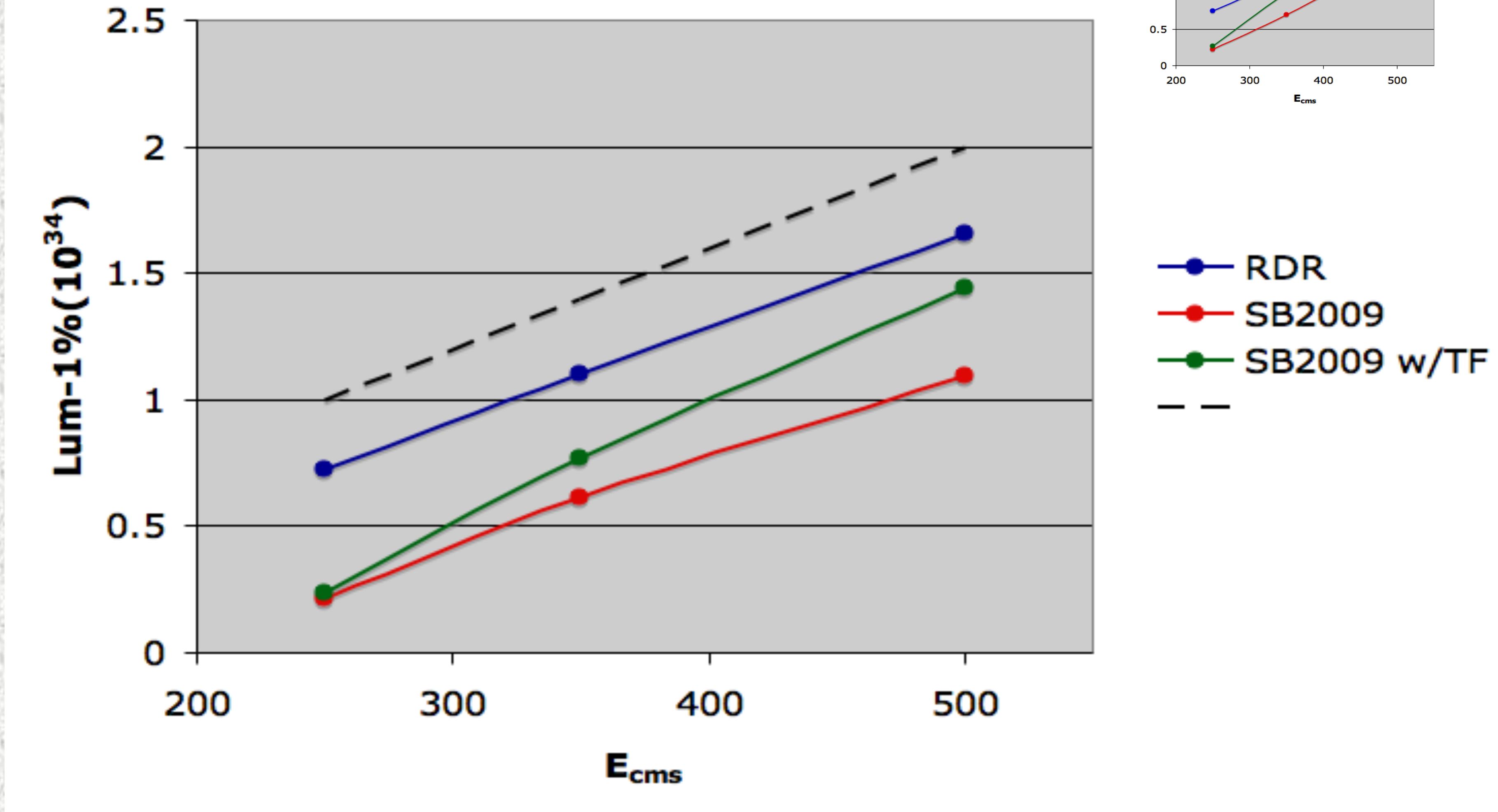
Luminosity vs. E_{cm}



Luminosity and Beamstrahlung

- Luminosity in the 1% energy peak



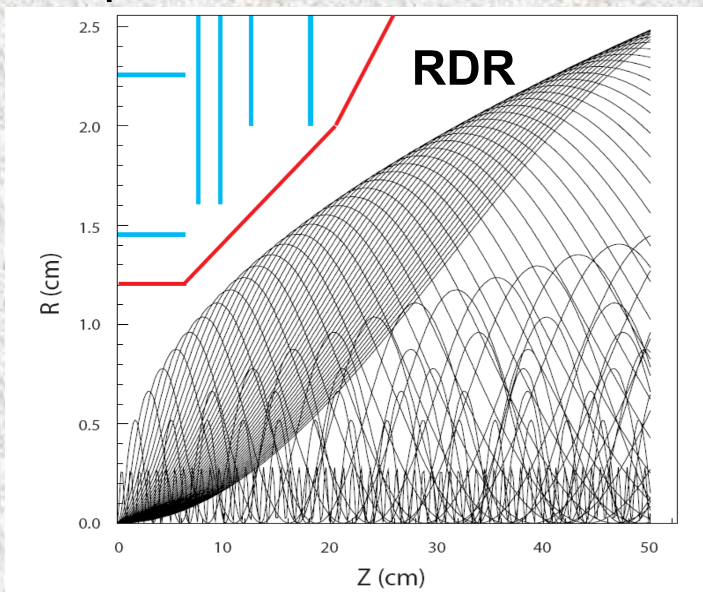


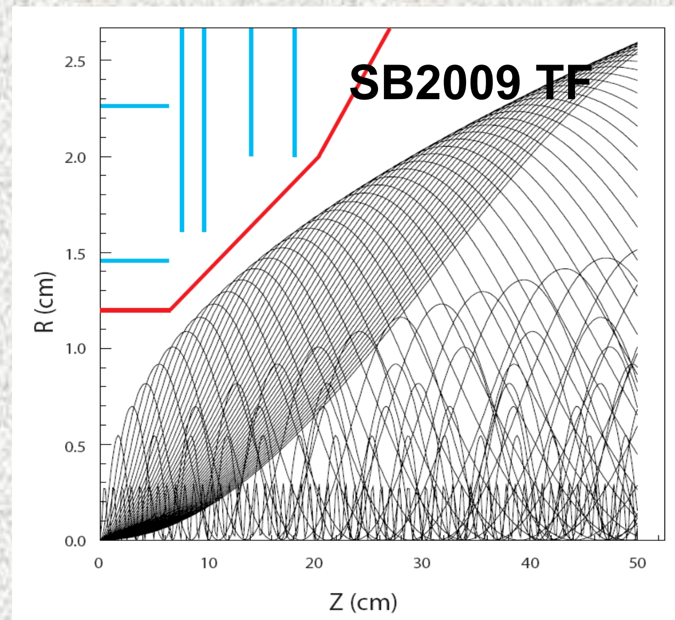
Beamstrahlung background

- The number of beamstrahlung pairs increases for SB2009, with or without traveling focus turned on
  - (T. Maruyama Guinea Pig study)

	E_{tot}(TeV)	No.($e^{\pm}$)	<E>($e^{\pm}$)
RDR	215	85.5k	2.5 GeV
SBTF	635	203k	3.1 GeV

- SiD beam pipe and the vertex detector are compatible with the SB2009 beam parameters





SB2009 w/o TF nearly identical to SB2009 TF

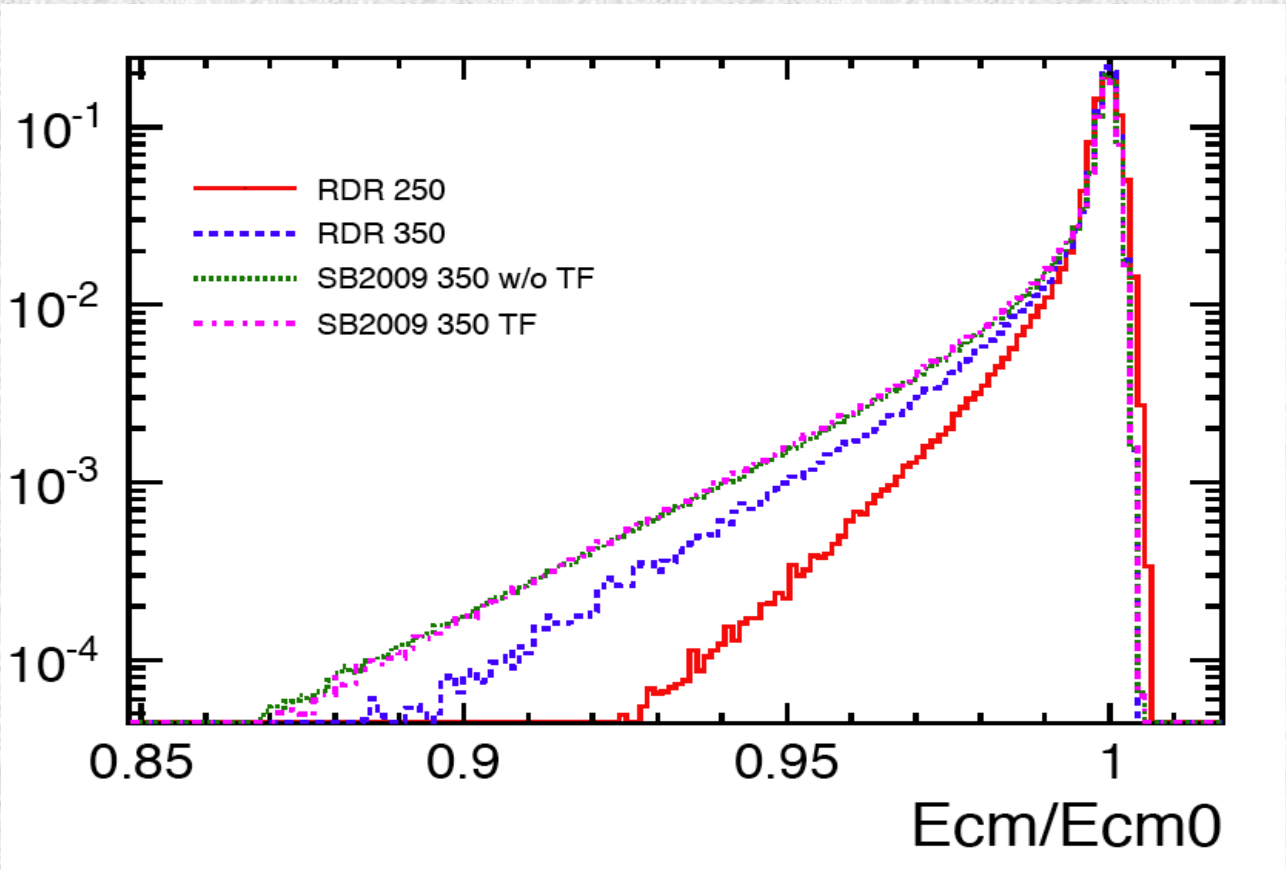
- Pairs will impact forward detection of electrons for two-photon veto - needs to be assessed (see slide)

SB2009 Studies

- **Three effects under study**
  - Reduced luminosity at low E_{cms}
  - Reduced effective luminosity due to Beamstrahlung
  - Increased backgrounds
- **Processes to assess impact**
  1. $e^+e^- \rightarrow \mu^+ \mu^-$ Higgs
     - Higgs mass
     - Higgs cross section
     - (important future study – Higgs branching ratios)
  2. Stau detection (forward electron vetoes)
  3. Low mass SUSY scenarios study
     - Snowmass SM2 benchmark
       - (m_0 = 100 GeV, $m_{1/2}$ = 250 GeV, tan β = 10, A_0 = 0, and sign μ = +) - similar to SPS1a point

1. Higgs Mass and Cross Section

- LOI studies assumed this is best done at E_{cm}=250 GeV, and assumed 250 fb^{-1}
- New Study of Higgs Recoil Mass @ 350 GeV - Hegne Li



Hengne Li

1. Higgs Mass and Cross Section

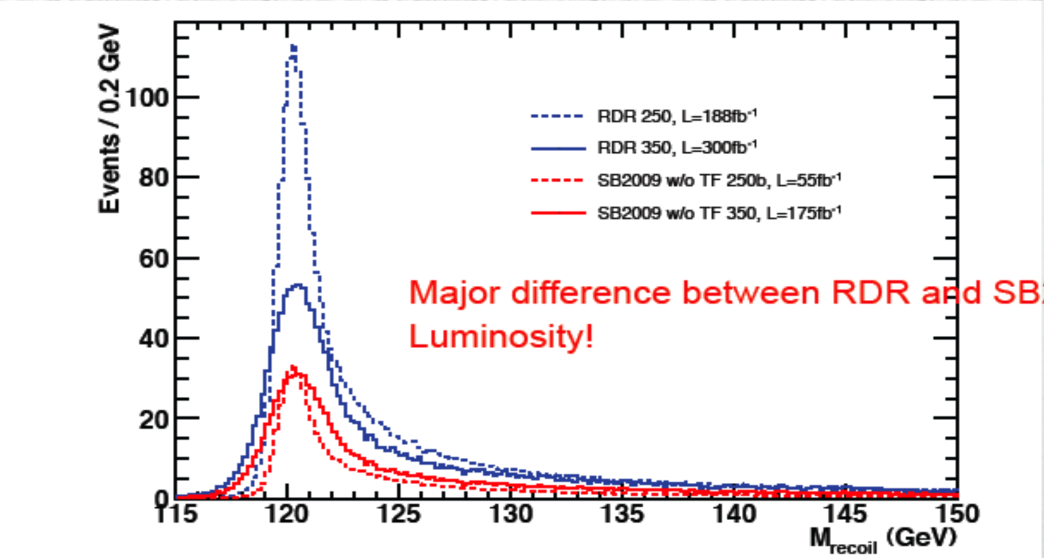
Beam Par	$\mathcal{L}_{int}$ (fb^{-1})	ϵ	S/B	M_H (GeV)	σ (fb) ($\delta\sigma/\sigma$)
RDR 250	188	55%	62%	120.001 ± 0.043	11.63 ± 0.45 (3.9%)
RDR 350	300	51%	92%	120.010 ± 0.084	7.13 ± 0.28 (4.0%)
SB2009 w/o TF 250b	55	55%	62%	120.001 ± 0.079	11.63 ± 0.83 (7.2%)
SB2009 w/o TF 350	175	51%	92%	120.010 ± 0.110	7.13 ± 0.37 (5.2%)
SB2009 w/ TF 250b	68	55%	62%	120.001 ± 0.071	11.63 ± 0. 75 (6.4%)
SB2009 w/ TF 350	250	51%	92%	120.010 ± 0.092	7.13 ± 0.31 (4.3%)

Coupling precision (cross section) better at 350 GeV than 250 GeV for SB2009

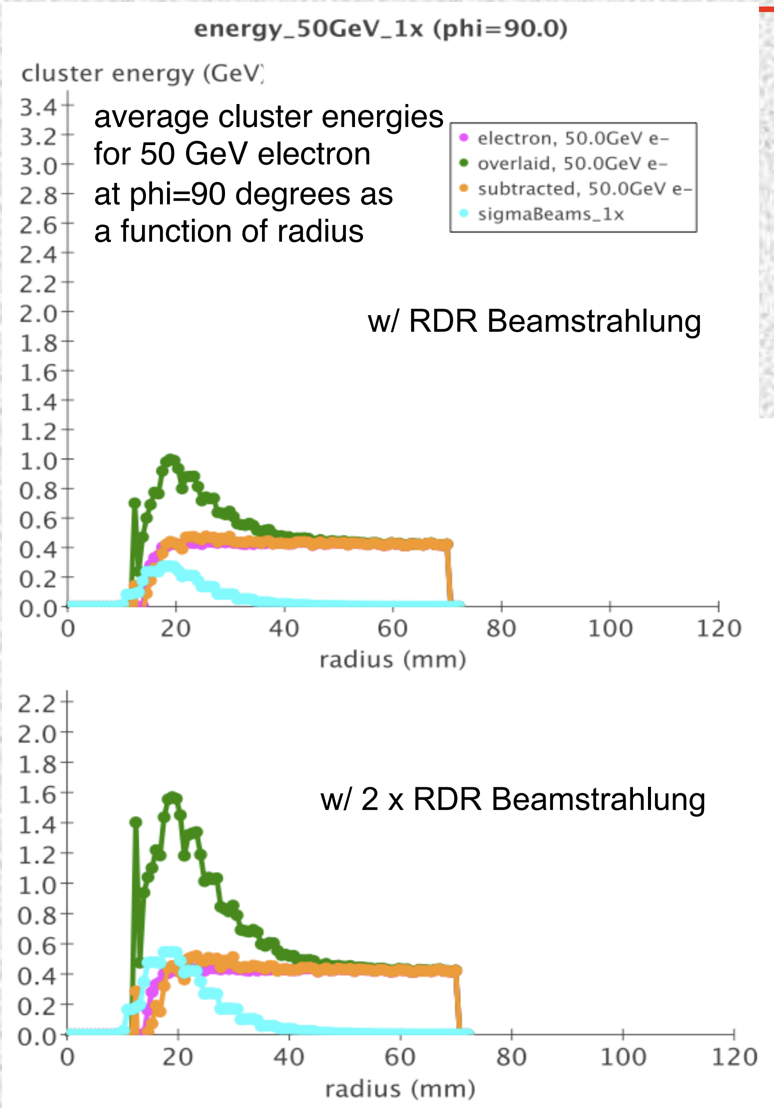
Higgs mass precision degrades by more than factor of 2 from RDR

- δM: 43 MeV → 92 MeV (wTF)
- δσ: 3.9% → 4.3% (wTF)

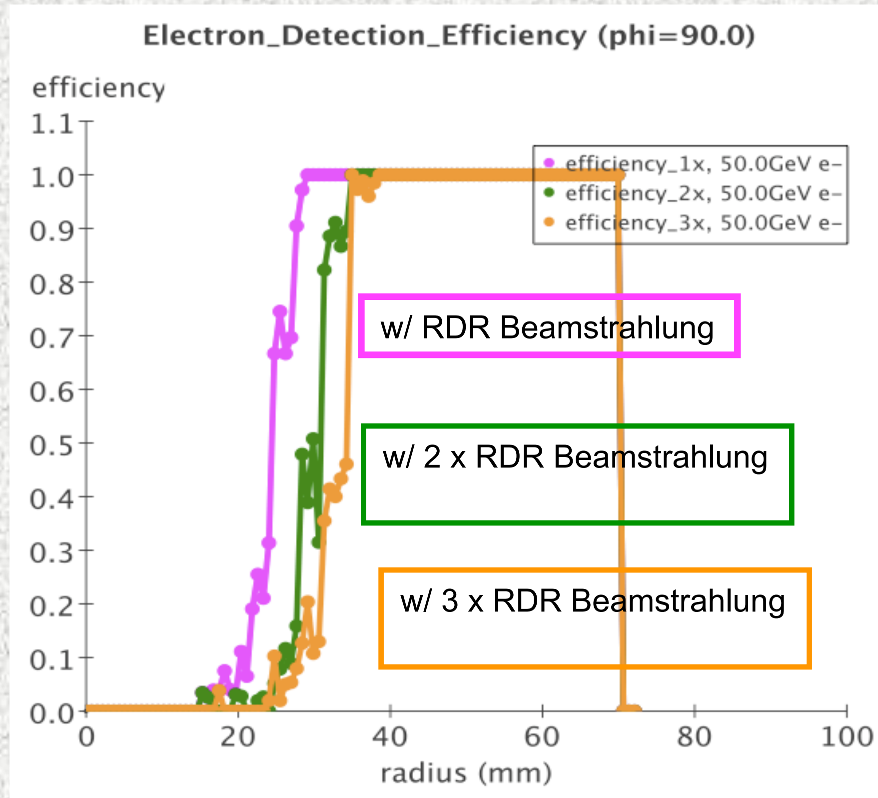
(Do theoretical considerations motivate sub-100 MeV Higgs mass precision?)



2. Forward electron detection



- Tagging $e^+e^- \rightarrow e^+e^- X$
  - Background to SUSY



G. Oleinik/U. Nauenberg

2. stau's at the SPS1a' point

Mikael Berggren
LOI ref- arXiv:0908.0876

- Benchmark point

$$e^+e^- \rightarrow \tilde{\tau}_1{}^+\tilde{\tau}_1{}^- \rightarrow \tau^+\tilde{\chi}_1^0\tau^-\tilde{\chi}_1^0$$

- Sensitive to beam backgrounds and detector hermiticity
- Underlines advantage of a collider that is tunable in energy and polarization
- For SPs1a’ ($M_{\tilde{\tau}_1} = 107.9$ GeV $M_{\tilde{\chi}_1^0} = 97.7$ GeV)
  - rather low mass-difference between the lightest stau and the LSP, giving a soft spectrum
  - rather low signal cross-section
  - mass of $\tilde{\tau}_2$ is 194.9 GeV

2. stau's at the SPS1a' point

- Three issues
  - Increased background pairs in the BeamCal might increase gamma-gamma background in the selected sample
  - Increased beam-background will reduce signal efficiency
  - Fewer events in the peak, and a broadened peak, might reduce the precision of the end-point measurement, and hence the mass determination
- Assumption - running time E_{cm} = 500 GeV, 500 fb^{-1}

2. stau's at the SPS1a' point

	Endpoint errors:		Cross-section errors:	
	stau_1	stau_2	stau_1	stau_2
	(107.9 GeV)	(194.9 GeV)	(158 fb)	(17.7 fb)
RDR	0.129 GeV	1.83 GeV	2.90%	4.24%
SB2009 wTF	0.152 GeV	2.10 GeV	3.52%	5.09%
SB2009 noTF	0.179 GeV	2.42 GeV	3.79%	5.71%

Mikael Berggren

- 15-20% degradation w/ TF
  - Primarily due to loss of signal

3. Low mass SUSY scenarios study

- Study of Snowmass SM2 point (~ SPS1a point)
  - hep-ex/0211002v1, P. Grannis

$(m_0 = 100 \text{ GeV}, m_{1/2} = 250 \text{ GeV}, \tan\beta = 10, A_0 = 0, \text{and sign}\mu = +).$

	M	Final state	(BR(%))			
$\tilde{e}_R$	143	$\tilde{\chi}_1{}^0 e$ (100)				
$\tilde{e}_L$	202	$\tilde{\chi}_1{}^0 e$ (45)	$\tilde{\chi}_1{}^\pm \nu_e$ (34)	$\tilde{\chi}_2{}^0 e$ (20)		
$\tilde{\mu}_R$	143	$\tilde{\chi}_1{}^0 \mu$ (100)				
$\tilde{\mu}_L$	202	$\tilde{\chi}_1{}^0 \mu$ (45)	$\tilde{\chi}_1{}^\pm \nu_\mu$ (34)	$\tilde{\chi}_2{}^0 \mu$ (20)		
$\tilde{\tau}_1$	135	$\tilde{\chi}_1{}^0 \tau$ (100)				
$\tilde{\tau}_2$	206	$\tilde{\chi}_1{}^0 \tau$ (49)	$\tilde{\chi}_1{}^- \nu_\tau$ (32)	$\tilde{\chi}_2{}^0 \tau$ (19)		
$\tilde{\nu}_e$	186	$\tilde{\chi}_1{}^0 \nu_e$ (85)	$\tilde{\chi}_1{}^\pm e^\mp$ (11)	$\tilde{\chi}_2{}^0 \nu_e$ (4)		
$\tilde{\nu}_\mu$	186	$\tilde{\chi}_1{}^0 \nu_\mu$ (85)	$\tilde{\chi}_1{}^\pm \mu^\mp$ (11)	$\tilde{\chi}_2{}^0 \nu_\mu$ (4)		
$\tilde{\nu}_\tau$	185	$\tilde{\chi}_1{}^0 \nu_\tau$ (86)	$\tilde{\chi}_1{}^\pm \tau^\mp$ (10)	$\tilde{\chi}_2{}^0 \nu_\tau$ (4)		
$\tilde{\chi}_1{}^0$	96	stable				
$\tilde{\chi}_2{}^0$	175	$\tilde{\tau}_1 \tau$ (83)	$\tilde{e}_R e$ (8)	$\tilde{\mu}_R \mu$ (8)		
$\tilde{\chi}_3{}^0$	343	$\tilde{\chi}_1{}^\pm W^\mp$ (59)	$\tilde{\chi}_2{}^0 Z$ (21)	$\tilde{\chi}_1{}^0 Z$ (12)	$\tilde{\chi}_1{}^0 h$ (2)	
$\tilde{\chi}_4{}^0$	364	$\tilde{\chi}_1{}^\pm W^\mp$ (52)	$\tilde{\nu}\nu$ (17)	$\tilde{\tau}_2 \tau$ (3)	$\tilde{\chi}_{1,2} Z$ (4)	$\tilde{\ell}_R \ell$ (6)
$\tilde{\chi}_1{}^\pm$	175	$\tilde{\tau}_1 \tau$ (97)	$\tilde{\chi}_1{}^0 q\bar{q}$ (2)	$\tilde{\chi}_1{}^0 \ell\nu$ (1.2)		
$\tilde{\chi}_2{}^\pm$	364	$\tilde{\chi}_2{}^0 W$ (29)	$\tilde{\chi}_1{}^\pm Z$ (24)	$\tilde{\ell}\nu_\ell$ (18)	$\tilde{\chi}_1{}^\pm h$ (15)	$\tilde{\nu}_\ell \ell$ (8)

3. Low mass SUSY scenarios Study

Table 1: Run allocations for the SPS1 Minimal Sugra parameters.

Beams	Energy	Pol.	$\int \mathcal{L}dt$	$[\int \mathcal{L}dt]_{\rm equiv}$	Comments
e^+e^-	500	L/R	335	335	Sit at top energy for sparticle masses
e^+e^-	M_Z	L/R	10	45	Calibrate with Z's
e^+e^-	270	L/R	100	185	Scan $\widetilde{\chi}_1{}^0\ \widetilde{\chi}_2{}^0$ threshold (L pol.) Scan $\widetilde{\tau}_1\ \widetilde{\tau}_1$ threshold (R pol.)
e^+e^-	285	R	50	85	Scan $\widetilde{\mu}_R{}^+\ \widetilde{\mu}_R{}^-$ threshold
e^+e^-	350	L/R	40	60	Scan $t\bar{t}$ threshold Scan $\tilde{e}_R\ \tilde{e}_L$ threshold (L & R pol.) Scan $\widetilde{\chi}_1{}^+\ \widetilde{\chi}_1{}^-$ threshold (L pol.)
e^+e^-	410	L	60	75	Scan $\widetilde{\tau}_2\ \widetilde{\tau}_2$ threshold Scan $\widetilde{\mu}_L{}^+\ \widetilde{\mu}_L{}^-$ threshold
e^+e^-	580	L/R	90	120	Sit above $\widetilde{\chi}_1{}^\pm\ \widetilde{\chi}_2{}^\mp$ threshold for $\widetilde{\chi}_2{}^\pm$ mass
e^-e^-	285	RR	10	95	Scan with e^-e^- collisions for $\tilde{e}_R$ mass

hep-ex/0211002v1, P. Grannis

~1000 fb^{-1} equivalent luminosity
(scaled by L ~ E)

3. Low mass SUSY scenarios Study

- Two possible strategies to adjust to lower luminosity capability of SB2009
  - Run longer at each point
  - Dividing running differently to reduce overall run time

- We have looked at the impact of ILC parameters on the physics program, assuming the same division of luminosity at selected E_{cm}

3. Low mass SUSY scenarios study

(a la Grannis)

Year	1	2	3	4	5	6	7
$\int \mathcal{L}dt$	10	40	100	150	200	250	250

hep-ex/0211002v1,
P. Grannis

- **Year 1** 500 GeV - if possible (10 fb^{-1})
- **Year 2-3** 500 GeV ~ 80 fb^{-1}
  - Achieve twice the ultimate errors on sparticle masses
- **Year 3** scan at 285 GeV 50 fb^{-1} (85 fb^{-1} equiv.)
  - Smuon threshold
- **Year 4** scan at 350 GeV 40 fb^{-1} (60 fb^{-1} equiv.)
  - Top, selectron, chargino thresholds
- **Year 4-5** complete 500 GeV run (total 335 fb^{-1})
  - Ultimate precisions
- **Year 6** scan at 270 GeV 100 fb^{-1} (185 fb^{-1} equiv.)
  - Neutralino and stau thresholds
- **Year 7** scan at 410 GeV 60 fb^{-1} (73 fb^{-1} equiv.)
  - Stau and smuon thresholds

Note -

Assume L ~ E

Not quite RDR

Also -

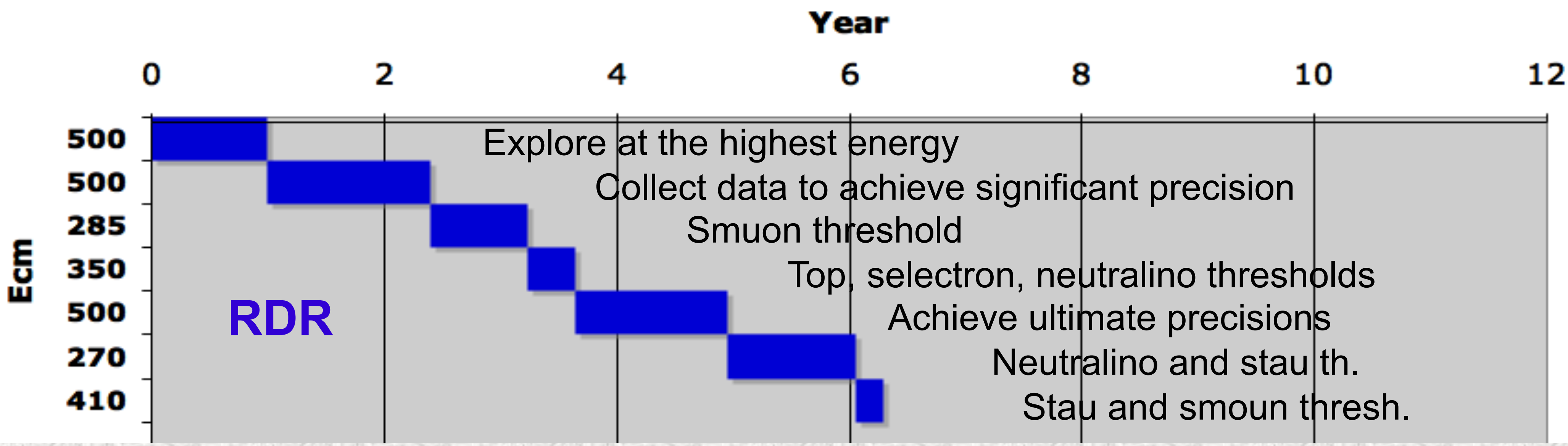
10 fb^{-1} Mz cal,

10 fb^{-1} e-e- (285),

90 fb^{-1} 580 GeV

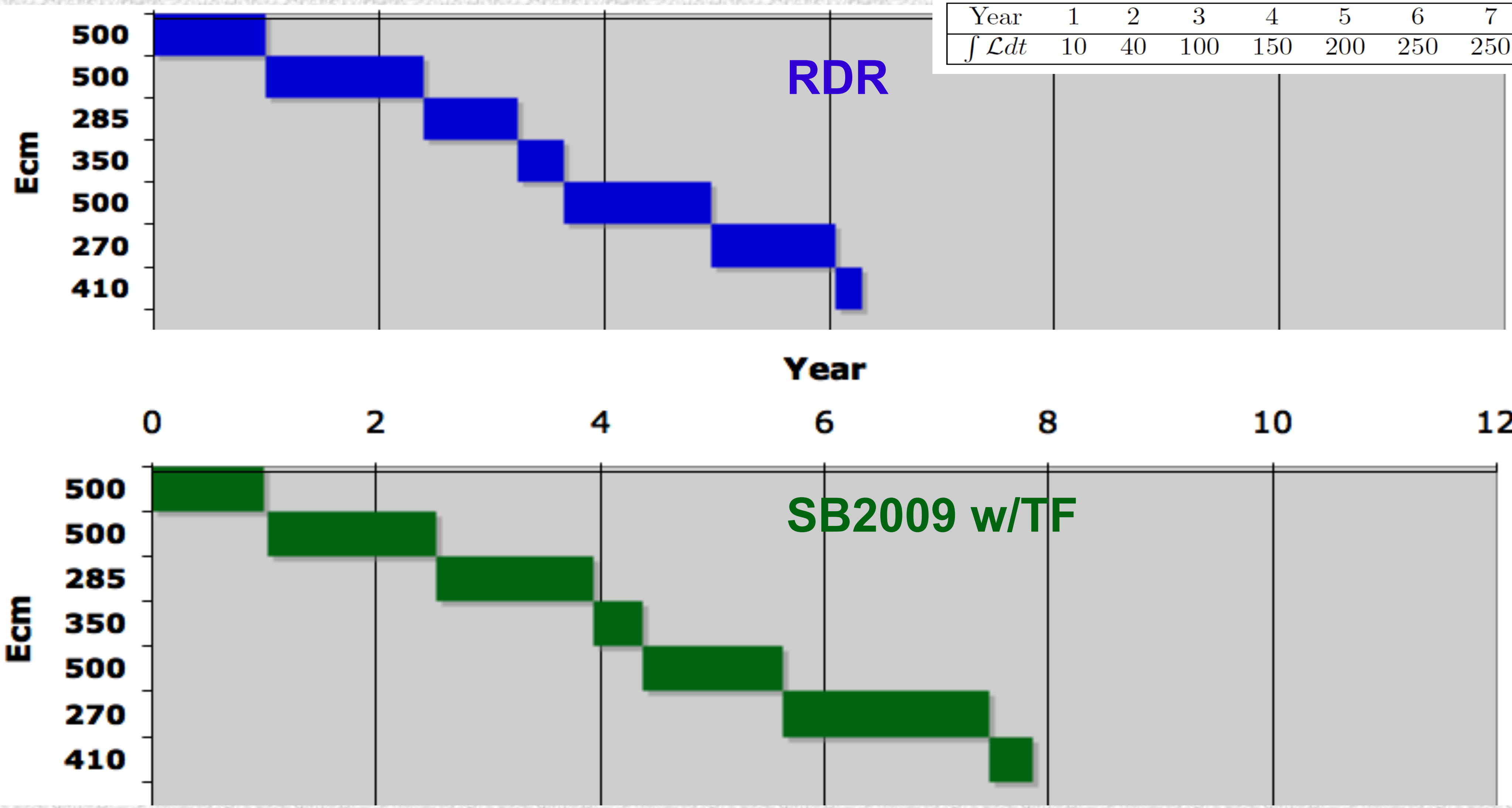
3. Low mass SUSY scenarios study

Year	1	2	3	4	5	6	7
$\int \mathcal{L}dt$	10	40	100	150	200	250	250



Note – these running periods represent average luminosity accumulation; the breaks in the running for machine work are not shown

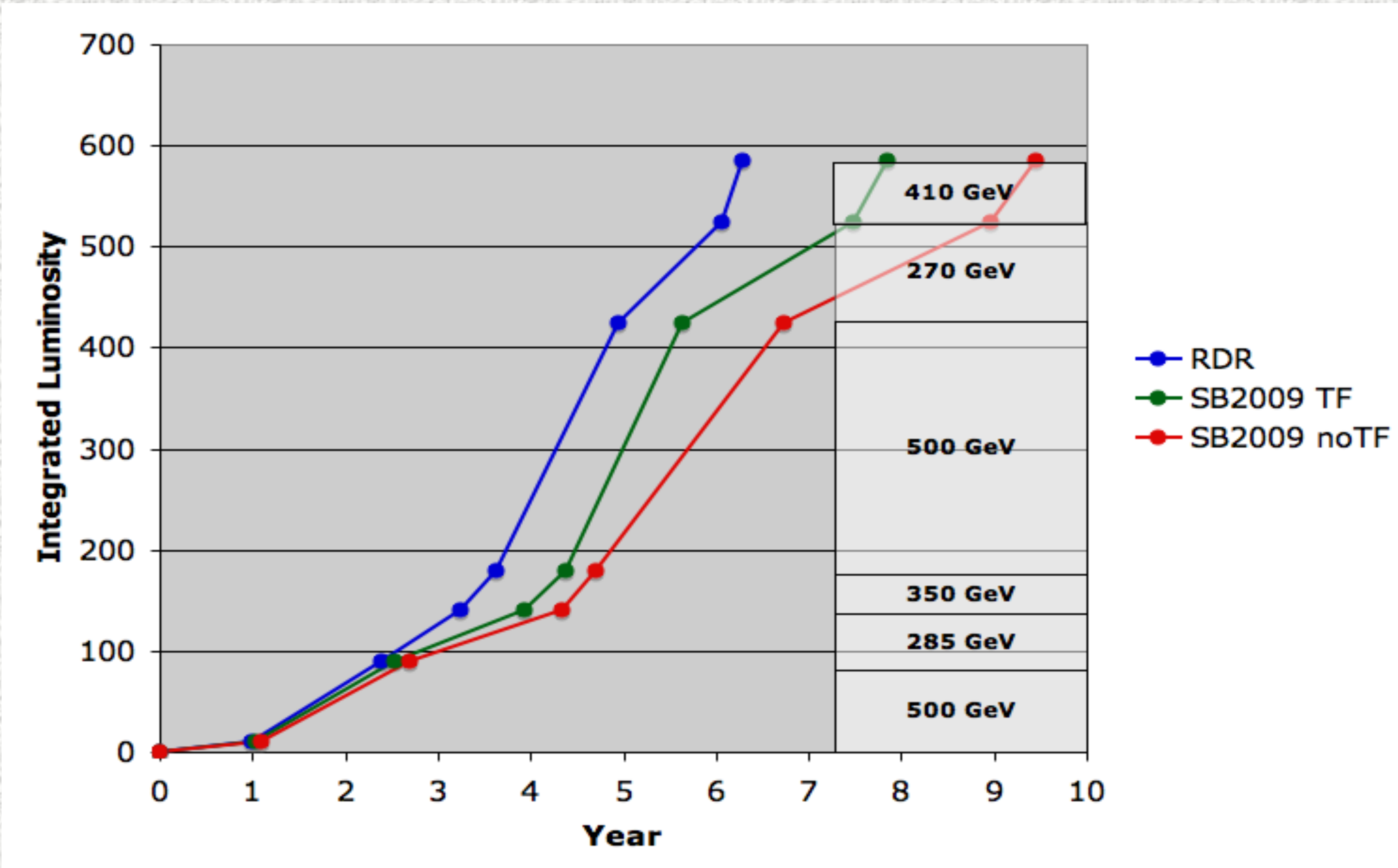
3. Low mass SUSY scenarios study



Year	1	2	3	4	5	6	7
$\int \mathcal{L}dt$	10	40	100	150	200	250	250

3. Comparion of RDR w/SB2009

(Low Mass SUSY Scenario)



Conclusions

- Several physics impacts of SB2009 have been investigated
  - Higgs mass and cross section

    δM: 43 MeV → 93 MeV

    δσ: 3.9% → 4.3%

    Run at 350 GeV w/ traveling focus
    Worse without TF
  - Stau detection

    15-20% degradation w/TF
  - Low mass SUSY scenario (an example)

    Stretched out run plan (~6 years → +1.5 years wTF, +3 years w/o)

    Can run strategy be streamlined? - scenario dependent
- Need to assess Higgs branching ratio (250 vs. 350 GeV), and investigate 350 GeV spin-parity analysis (as alternative to threshold cross section measurement)
- A significant lower energy luminosity reduction may have very negative impact on the ILC program

MDI Session - SB2009 Discussion

Sunday 11 am

- L(E) optimization discussion -- Andrei Seryi
- SB2009 Higgs mass and cross section measurement study -- Hegne Li
- Status of stau study -- Mikael Berggren